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NEOPROTEROZOIC TECTONO-METAMORPHIC EVOLUTION OF HAFAFIT DOME "A" AND THE ABUTTING SHAIT OPHIOLITIC MÉLANGE DOMAIN AT GABEL MUDARGAG AREA, CENTRAL EASTERN DESERT, EGYPT

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The Mudargag area, 740 km^2 builds up two Neoproterozoic tectono-stratigraphic units separated by a NW trending subhorizontal thrust plane along which deformed rocks from both units are confined. The lower infrastructural unit is represented by the northern dome "A" of Wadi Hafafit culmination which forms a macroscopic oval-shaped asymmetrical antifromal domal structure with a fold axis extends over 10 km in a NW-SE direction. It is differentiated into four structural subunits composed of interlayered sequences, mainly of para-granite gneisses, psammitic gneisses and para-amphibolites with medium to high-grade metamorphic facies. Granite gneisses and psammitic gneisses dominate the lower and the upper subunits, respectively, para-amphibolites dominate the second subunit, whereas the third subunit has subequal proportions of psammitic gneisses and amphibolites. The upper suprastructural unit is represented by Shait ophiolitic mélange domain (SOMD), which comprises deformed normally faulted thin-skinned napped sequence of low-grade metamorphosed volcano-sedimentary island-arc type assemblages incorporating dismembered ophiolite and partially carbonated serpentinite fragments. Petrographic examinations carried out on both dome "A" and SOMD show distinct evidences of polyphase deformation (D_1-D_3) in addition to tow metamorphic events (M_1-M_2). Field data revealed that the exhumation of the Hafafit culmination domes to which the present dome "A" is considered and the large-scale crustal extension of SOMD run within a left-lateral dominated transpressional wrenching of Najd Shear System.

Keywords: Mudargag, Hafafit, infrastructural, suprastructural, Shait ophiolitic mélange

1- INTRODUCTION

The Eastern Desert basement of Egypt represents the northwestern exposure of the Neoproterozoic Midyan–Eastern Desert terrane belonging to the northeast African Orogeny. It consists of low-grade regionally metamorphosed a collage of dismembered ophiolite suites, island-arc, back-arc, volcanics and volcanoclastics, unmetamorphosed molasse-type sediments, as well as considerable granitoid intrusions (El-Gaby et al., 1988; Fritz et al., 2013). These lithologic groups were evolved and cratonized during the Pan African orogeny (900-550 Ma) either through a process of horizontal crustal accretion (Gass, 1981; Yail, 1983; Kröner, 1985) or through an oblique collision of East and West Gondwana continental masses (Stern, 1994; Fritz et al.2013). Moreover, it is characterized by the occurrence of some medium to high-grade gneissic sequences exposed as large asymmetrical antiformal structures, tectonic windows or culminations, structurally separated from the adjoining low-grade Pan-African ophiolitic mélange napped domains by structural contacts (Shackleton, 1980; Kröner et al., 1987; El-Gaby et al., 1988; Greiling et al., 1988; Khudeir et al., 1995, 2008; Fritz et al., 1996, 2002; Fowler et al., 2001; Fowler and El-Kalioubi, 2002; Makroom, 2017).

The Wadi Hafafit culmination (WHC) represents one of these prime occurrences in the Egyptian basement and is exposed at its boundary between the southern and the central parts. It is structurally discriminated into five separated gneissic domes, labeled A-E core gneisses each one has distinct geometry and aerial extent (El-Ramly and Greiling, 1988). It can be geometrically and structurally correlated with the Meatiq, Sibai, El-Shalul, Betan and Wadi Kid gneissic domes exposed all over the Egyptian basement and Sinai. Their available radiometric age data derived from migmatic gneisses and amphibolites are clustered around two peaks at 750 and 650 MA (Stern and Hedge, 1985; Kröner et al., 1994; Loizenbauer et al., 2001 Heikal, 2003). These Neoproterozoic ages contrast the earlier views (Habib et al., 1985; El-Gaby et al., 1988) considering these gneiss domes as autochthonous basement, affiliated to early Proterozoic protoliths.

The exhumed WHC domes particularly the dome "A" have been investigated by several authors, namely (Greiling et al. 1988; El-Gaby S. 1988;

Greiling and El-Ramly 1990; Hassan and Hashad 1990; Rashwan 1991; El-Ramly et al. 1993; Greiling 1997; Fowler, A. R., & El Kalioubi, B. 2002; Heikal 2003; Khudeir et al. 2008; El-Kazzaz, Y.A., 2009; Fowler and Osman 2009; Shalaby, 2010; Asran & Kabesh, 2012; El-Enen et al. 2016; Makroum 2017). In spite of these efforts, only some agreement has been reached, especially with regard to the mechanism of their exhumation and structural evolution.

The present work deals with the results of the detailed field mapping, petrography and structural characteristics of the Mudargag area (Figs.1 and 2), which can be described as a tectono-stratigraphic sequence, displaying the presence of two structural units viz a lower infrastructural unit represented by the northern dome "A" of WHC structurally overlain by a suprastructural unit consists of Wadi Shait and Wadi Nugrus ophiolitic mélange domains. The study through some light on the structural fabrics and their deformational history, of the composing structural units.

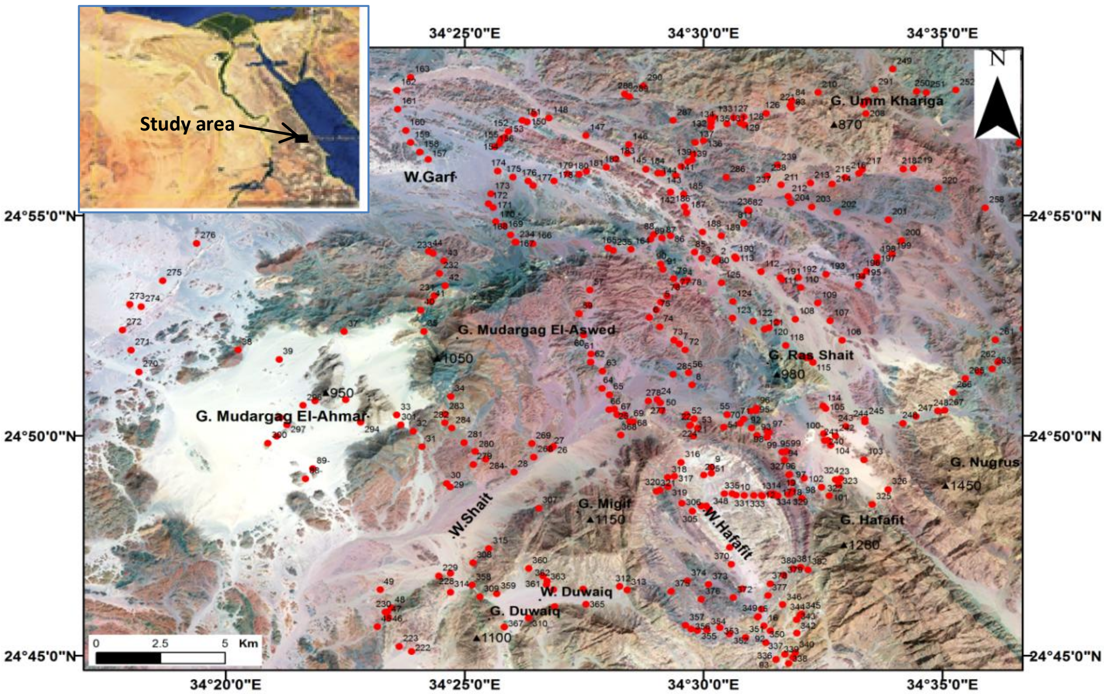


Fig. 1: Landsat image of the studied area showing the location of the selected samples.

2-GEOLOGICAL SETTING

The studied Mudargag area lies at about 70 km southwest of Marsa Alam on the Red Sea (Fig.1). Its lower infrastructural unit represented by the dome "A" geometrically forms a NW-SE trending asymmetrical doubly plunging antiformal structure with gneissic foliation dips steeply to the NE in the northeastern limb and moderately to the SW in the southwestern limb but plunges moderately toward the NW and SE directions (Fig. 2). It is separated from the neighboring Nugrus ophiolitic mélange domain (Greiling et al., 1988; Makroum, 2017) from the NE by steeply dipping sinistral strike-slip fault zone referred to as Nugrus strike-slip fault which strikes NW parallel to the Najd fault system (Stern and Hedge, 1985), and from Shait ophiolitic mélange domain (SOMD), on the N, NE and NW by a high-angle normal fault zone known as Shait normal fault striking NE-SW and dipping at 60°-65° NW underneath SOMD. The down faulting blocks of the Shait ophiolitic mélange are brittelely fractured into subparallel low-lying sliced linear ridges, within a zone up to 1 km wide, running parallel to the northern dome "A" boundary. The southern boundary of the dome "A" is marked by the presence of an oblique sinistral strike-slip fault, running NE-SW and dipping steeply southwestwards underneath the gneiss-amphibolite interlayered sequence of the southern dome B of WHC.

The tectonostratigraphy of the dome "A" is further differentiated in the field into four structural subunits separated by fault contacts as follows (Fig. 3a): subunit 1 is the lowest core one. It consists of a high-grade metamorphic interlayered sequence of granite gneisses (variably migmatic), and subordinate proportion of amphibolite, followed upwards by subunit 2 which builds up a medium to high-grade layered sequence of banded amphibolites and granite gneiss (<20 cm, thick). In turn, subunit 2 is followed up wards by subunit 3 which is composed of medium-grade repetitive alternated sequence of psammitic gneiss and amphibolite layers. Lastly comes the upper subunit 4 which is represented by medium-grade interlayered sequence of psammitic gneisses and minor amphibolites.

The tectonostrtigraphy of the infra- and suprastructural rock units and the intruding igneous complexes of the studied Mudargag area is as follows:

suprastructure

a) Mudargag El-Ahmar calc-alkaline to alkaline granite and b) Nugrus granite complexes. — **Late to post-orogenic granites**

--- Intrusive contact -----------------------

- Low-grade ophiolitic mélange napps of
a) Shait ophiolitic mélange and b) Nugrus ophiolitic mélange. — **Ophiolitic mélange nappes**

-- Shait normal fault -----------------

infrastructure

Dome "A":

4) Medium-grade interlayered sequence of psammitic gneisses and minor amphibolites.
3) Medium-grade alternation of psammitic gneiss and amphibolite layers.
2) Medium to high-grade amphibolite-granite gneisses interlayered sequence with dominance of amphibolite.
1) High-grade granite gneisses amphibolite interlayered sequence with dominance of granite gneisses.

Detailed field and petrographic investigations of the lithologic subunits of the dome "A" indicate that they were essentially derived from sedimentary parentages; metamorphosed rocks of igneous parentage are infrequent. Hereafter is a brief description of the whole sequence starting from the lower subunit and working up:

Subunit 1 forms the lowest subunit in the structural succession of the dome "A" and is composed of granite gneiss and amphibolite interlayered sequence characterized by low-relief landscape or topography. Generally, the granite gneiss rocks are the dominant and form more thick layers than those of the amphibolites (Fig.4-a). Both granite gneisses and amphibolites are generally foliated, lineated and distinctly folded around a NW-SE trending axial surface giving rise to an asymmetrical antiformal structure with a SW moderately dipping axial plane (Figs. 2 and 3a). Moreover, they exhibit a regular variation in the degree of migmatization that can be realized in moving from the limbs toward the core of the antiformal area, where the metamorphosed rock varieties grade from metatexites with layered and folded migmatite structures (Figs. 4- b,c) into diatexites characterized by homogeneous nebulitic and ophthalmic migmatites (Fig. 4-d,e). This variation is generally accompanied by gradual increase, in the grain size and progressive fading of the gneissic structure. Both metatexites and diatexites are occasionally intruded by pegmatite and trondhjemite dykes as well as quartz veins, up to several meters in length, and are occasionally folded and/or

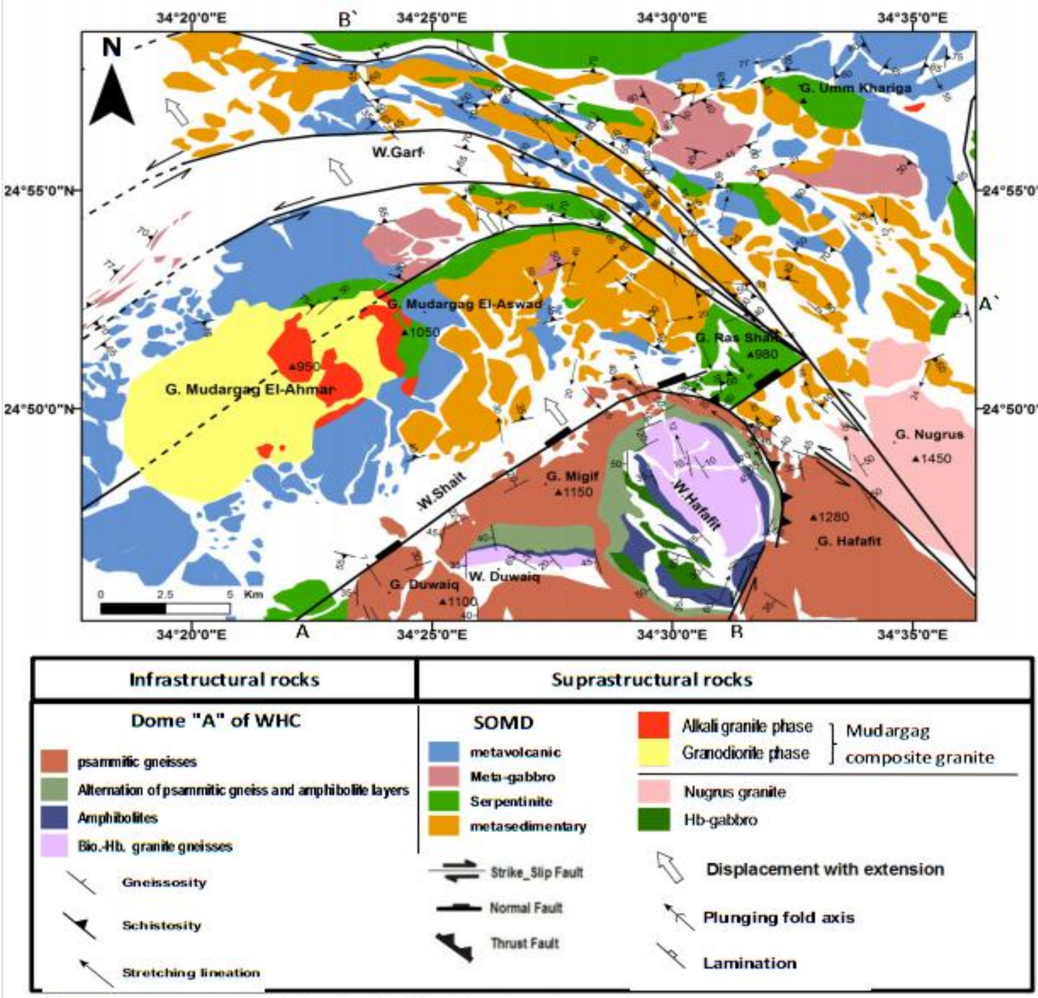


Fig. 2: Structural map of the studied Mudargag area.

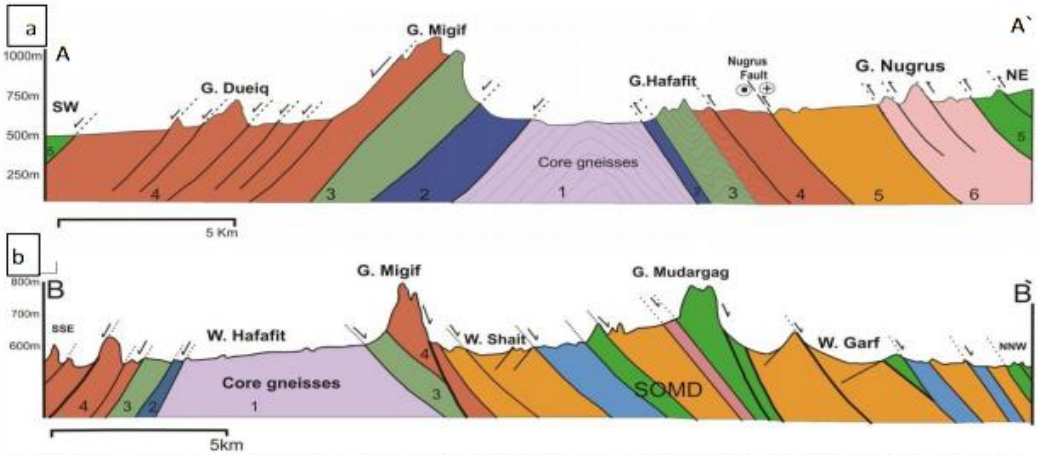


Fig.3: (a) A-A` and (b) B-B` schematic cross-sections to illustrate the structural setting in two profiles crossing the structural map in fig.2.

boudinaged (Figs. 4-f). The pegmatite dykes locally contain coarse grains of garnet and irregular amphibolite and gneiss xenoliths with variable shape and size (Figs. 4-g,h). The granite gneisses and amphibolite of this subunit were found to be regionally metamorphosed (M_1) under medium to high P-T conditions as inferred from (a) the presence of almandine garnet– sillimanite and both Ca- and K-feldspars (b) the wide-scale development of anatectic gneissose tonalites and minor granodiorites in the core of the dome "A".

Subunit 2 also builds up a low-relief package of thinly banded migmatized amphibolite layers, up to 5 m thick, less commonly intercalated by thinner para-granite gneiss layers, up to 1 cm thick. This metamorphosed package generally crops out as disconnected low relief ridges along the flanks of the core sequence of the subunit 1. The amphibolite layers display dark grey colour, open and complex folding (Figs. 4-i, j) and strong foliation with dominance of metatexitic migmatite type. In few cases, the amphibolite layer is partially assimilated by intrusive hornblende gabbro dykes (Fig.4-k). The granite gneiss is mineralogically characterized by the occurrence of biotite, hornblende and occasional almandine garnet (Fig. 4-l).

Field and petrographic investigations showed that the layered amphibolite package of the western part of the subunit 2 lying to the west of the Wadi Hafafit is superimposed by a low-pressure type of metamorphism caused most probably by a concealed hornblende gabbro intrusion at depth. This is evidenced by the occurrence of several dyke-like masses of cataclased unmetamorphosed hornblende gabbro and porphyritic hornblende basalts intruding the layered amphibolites within a zone up to 300 m wide. Such observation argues against the suggestion of Makroum (2017) which considers these cataclased hornblende gabbros as belonging to the old ophiolitic calc-alkaline metagabbros. The low-pressure thermal metamorphism will be discussed separately, in a separate publication.

Subunit 3, is lithologically composed of nearly subequal amounts of repetitive alternation of intensely foliated psammitic gneiss and amphibolite layers forming medium to high-relief elongated relatively narrow ridge surrounding the low-lying topography of subunit 1 and 2. The part of this unit cropping out in the eastern limb of the dome "A" antiform is intersected by NW-SE trending shear zones running parallel to the strike of the foliation of the composing rocks and by occurrence of few mesoscopic overturned and rootless drag folds. These shear zones occasionally incorporate foliated carbonatized serperntinite and metagabbro lenses, 10-20 m long by 3-5 m thick. The overturned mesoscopic folds have axial planes moderately dipping east to southeast direction.

Subunit 4, generally contrasts the above mentioned subunits as it forms markedly and widely extended medium to high-relief distinctive outcrops generally enveloping the dome "A". Moreover, it is characterized by the occurrence of the conspicuous positive topographic peaks exampled by Gabal Hafafit and Migif (Fig. 3-a) which can be easily distinguished from long distances.

Lithologically, this subunit consists of thick layers of psammitic gneisses occasionally intervened by elongated bodies of layered amphibolites. The psammitic gneiss layers are composed mainly of variable amounts of quartz, plagioclase, and microcline with minor proportions of biotite and/or hornblende. Garnet and muscovite are rare. The psammitic gneiss outcrops forming the western limb of the dome "A" are subjected to SW trending extension as they are intersected by a set of NW striking normal faults generally dipping steeply toward the SW (Fig. 3-a). In turn, the psammitic gneiss exposuers laying to the northeastern marginal zone of the dome "A" are intensely deformed and deeply eroded due to their intersection by several smaller shear zones branched off from the easterly located NW-SE trending Nugrus major shear (Fig. 2). In addition, the exposures locally incorporated subparallel NW-SE trending discrete lensoidal masses of ductilely deformed serpentinites, schistose metasediments, metavolcanics and amphibolites. Detailed field work, shows that these structural subunits indicators common in the overlying Pan-African cover nappes of the Shait and Nugrus indicate a NW direction of tectonic transport which is clearly indicated by rootless tight isoclinal overturned and recumbent mesoscopic folds, drag and asymmetrical minor folds (Figs. 4- m, n). This direction runs concordantly with the direction given by the kinematic ophiolitic mélange domains.

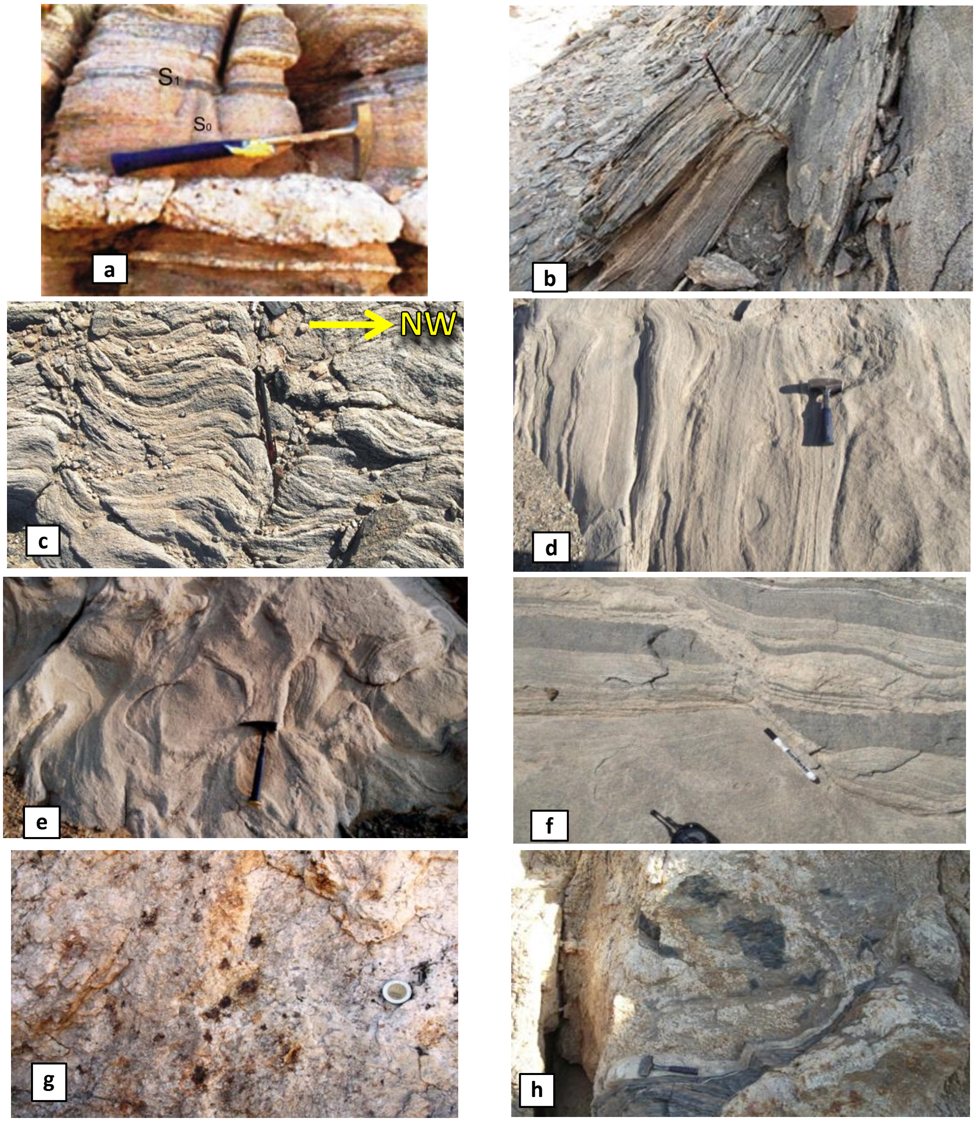
Ophiolitic mélange unit. This structural unit is exposed at the northern and northeastern portions of the map area. It is differentiated in the field into two domains referred to as: 1) Shait ophiolitic mélange domain and 2) Nugrus ophiolitic mélange domain. Both domains are characterized by a NW tectonic transport direction indicated by asymmetric minor folds as well as S-C and S-C` hear bands prevailed in the imbricated metavolcanic, serpentinite, and metasediments (Figs. 5-a,b,c).

(1)The Shait ophiolitic mélange domain, 400 km^2, is separated from the southern juxtaposed dome "A" by Wadi Shait major normal fault which extends E-W to ENE and generally dips at 55°- 60° NNW to NE (Fig. 5-d,e). The downthrown parts of Wadi Shait ophiolitic mélange occurring along the Wadi Shait fault plane are locally intercalated by deformed elongate slices, up to kilometers long and several tens of meters wide, slided down from the top part of subunit 4 of the dome "A". The Shait ophiolitic mélange nappes are separated from the Nugrus ophiolitic mélange domain at the NE part of map area by a sinistral strike-slip shear zone, which represents the NW extension of the master Nugrus shear. On the other hand, the northern and western boundaries of the Wadi Shait ophiolitic mélange lie outside the limits of the map area.

The Shait ophiolitic mélange domain constitutes folded imbricate nappe assemblages (Fig. 5-f) consisting mainly of low-grade metamorphosed ophiolitic and island arc volcanic blocks intervened by slices or sheets of layered low-grade metamorphism mudstone, siltstone, pebbly siltstones and polymectic conglomerates (Figs. 5-g,h). The ophiolite blocks include serpentines, metagabbros, metabasalt and andesite pyroclastics. The ophiolitic serpentines form partially to wholly carbonatized blocks covering areas with several square meters up to conspicuous mountainous ridges as those forming Ras Shait and Mudargag El-Aswad.

Detailed field observation indicates that the Shait ophiolitic domain was subjected to a northwestward crustal transtension related to the Nugrus master fault. This is illustrated by the intersection of the domain by a series of subparallel extension oblique faults and graben-structure running parallel to the northern boundary of the dome "A" (Fig. 2-b); the post-orogenic composite calc- alkaline to alkaline granite intrusion of Gabal Mudargag El-Ahmar is clearly intruding along the southwestward continuation of one of these normal faults (Fig. 2).

(2) The Nugrus ophiolitic mélange domain lies to the NE of the map area and extends toward east beyond its limits. Structurally it forms a NW-trending sequence of imbricate thrust nappes with lithologic assemblages and grade of metamorphism similar to that of Wadi Shait ophiolitic mélange. The included part in the study area, 200 km^2, is intruded by the NW-SE elongation of the late to post- orogenic Nugrus granite mountainous ridge.



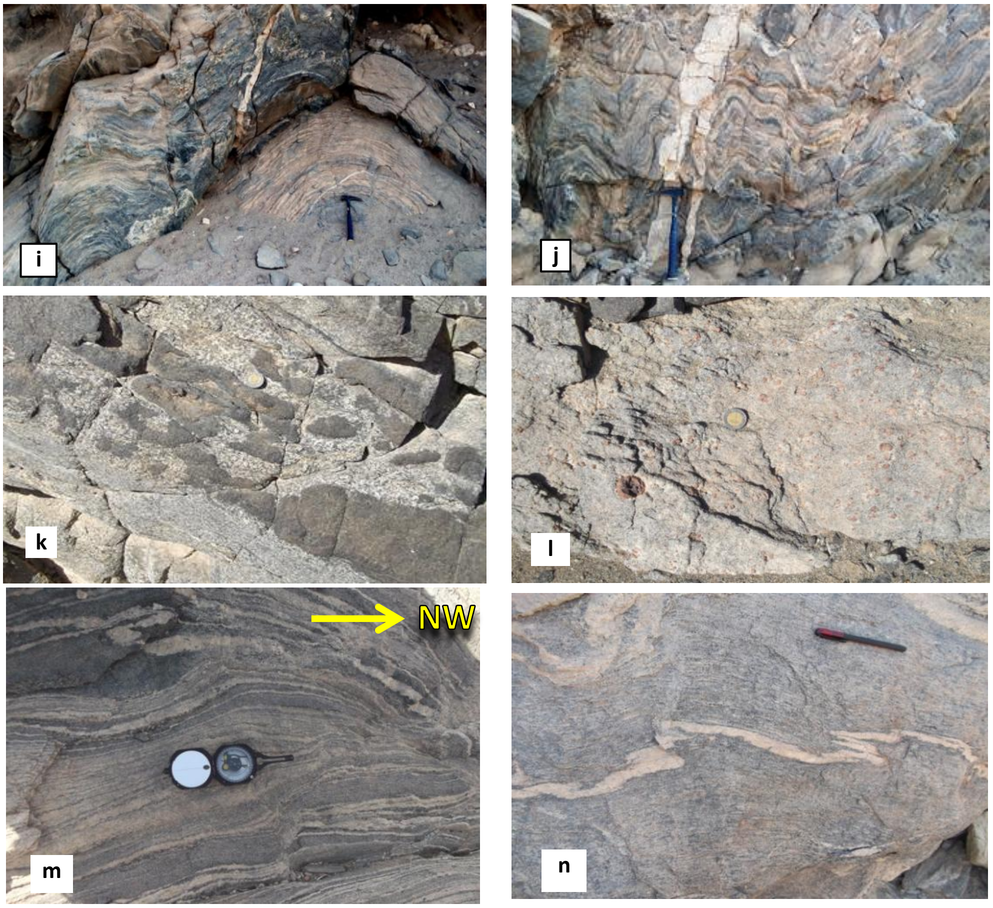


Fig. 4: Field photos of the structural subunits building up the dome "A". (**a**) Intercalation layering high-grade para-hornblende granite gneisses (light) and amphibolites (dark). Note the general conformable relation between layering (S_0) and foliation (S_1) inherited from the regional metamorphism (M_1), also note the injection of coarse pegmatite vein parallel to layering (S_0) (**b**) Layered metatexitic migmatite type injected by quartzfeldspathic leucosome. Note the intersection of the layer structure by mesoscopic normal fault causing small dragging of the layers. (**c**) An asymmetrically folded layered migmatic amphibolites showing top to NW tectonic transportation. Note the intersection of the folds by nearly subparallel fractures due to their northwest-ward stretching. (**d**) Diatexitic migmatites intersected by narrow veins of quartzfeldspathic leucosome. Note the diffuse boundaries between the tonalitic gneiss (neosome) and hornblende gneiss paleosome (dark). (**e**) Ophthalmic diatexitic migmatites in hornblende granite gneisses. (**f**) An association of hornblende granite gneiss and amphibolite interlayers injected by pegmatite bands undergoing normal faulting and boudinaging parallel to the layering structure. (**g**) Scattered garnet crystals

in a minor intrusive mass of granite pegmatite intruding subunit2. (**h**) Migmatic amphibolitic xenoliths in granite pegmatite dyke. (**i**) Openly folded metatexitic layered migmatic amphibolites dissected by quartz veins. (**j**) Complexly folded metatexitic layered migmatic amphibolites dissected by boudinaged quartz veins. (**k**) Partially dissolved (assimilated) amphibolites by an intrusive gabbroic magma. (**l**) Medium-grained foliated para-gneiss in subunit 1 rich in biotite and idiomorphic garnet crystals. (**m**) Rootless isoclinal folds in migmatic amphibolites showing transportation to NW. (**n**) Foliated para-amphibolite of subunit 2 injected by quartz feldspathic leucosome veins showing left-lateral sense of movement. Photograph taken NE of the dome "A" margin.

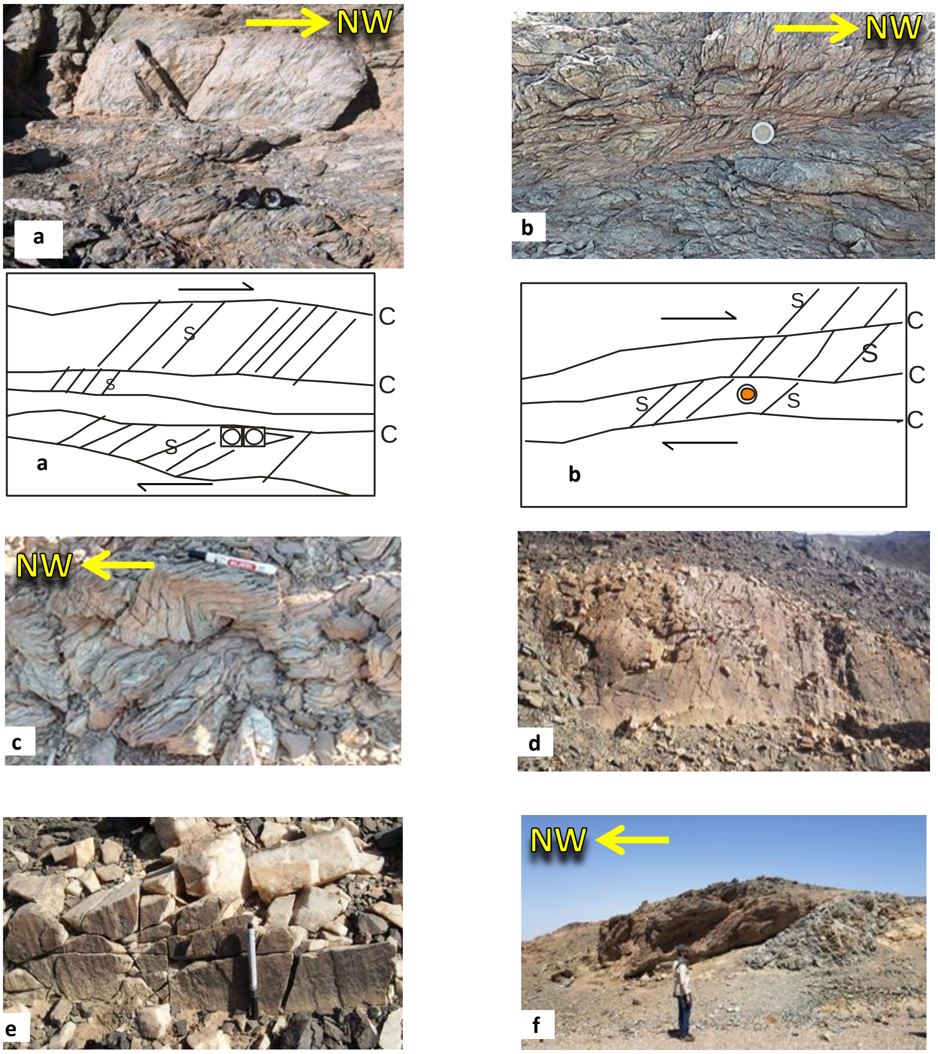


Fig. 5: Field photos of the areas of Shait and Nugrus ophiolitic mélange domains: (**a, b**) S-C fabric in schistose metasediments showing a top- to- the NW tectonic transport. (**c**) NW-SE verging a symmetrical minor fold in the Shait ophiolitic mélange domain showing transportation to NW. (**d, e**) Views showing development of polished (**d**) and steeply striated surfaces (**e**) in the Shait normal fault zone marking the tectonic contact between Shait ophiolitic mélange and the dome "A" structure. (**f**) A view shows part of an imbricated sliced stack of Shait ophiolitic mélange represented by basal serpentinites, followed wards up by metagreywackes and topped by metabasalts. (**g**) Pencil cleavage structure produced by intersection of horizontal metasiltstone strata with steeply inclined fractures set. (**h**) Intensely deformed metaconglomerates with flattened pebbles dipping 9° to the NW direction of the tectonic transport.

3-STRUCTURAL DATA

The present work concerns with the extensional fabrics or the geometrical analyses of the measured planar and linear structural data of the dome "A" and Shait ophiolitic mélange domain. The Nugrus ophiolitic mélange is not included in the present work since its most part lies outside of the map area. The area of the dome "A" is divided into four distinct structural sectors; diagrams A, B, C, and D, for the northern, eastern, southern and western parts; respectively, whereas the remaining E diagram covers Shait ophiolitic mélange domains (Fig.6).

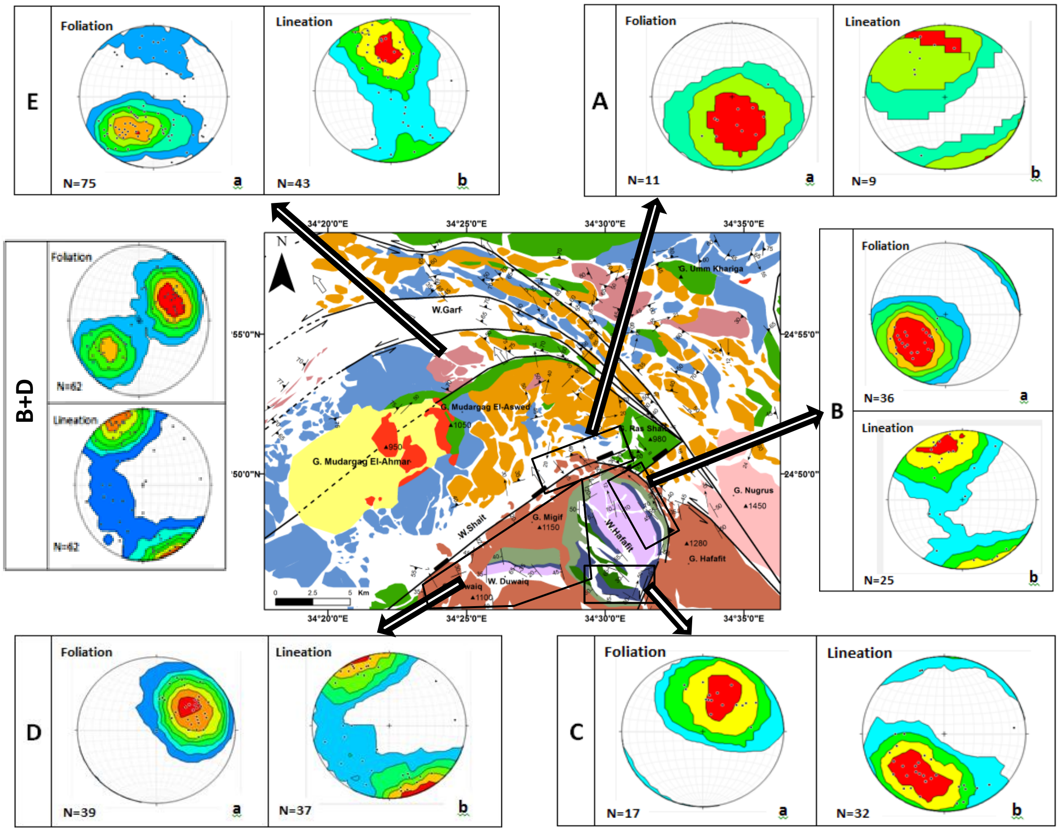


Fig. 6: Structural map of the studied Mudargag area showing the locations of planar and linear structural field data.

<u>The northern structural sector (A) of the dome "A"</u>. The exposed lithologic subunits of this sector are intervened by the NW-SE trending of Wadi Hafafit, variably deformed, and largely transformed into mylonite, ultramylonite and schists particularly along discrete shear zones dissecting the dome "A" and its schistose carapace which is structurally dipping northwards underneath Shait ophiolitic mélange domain. The structural lithologic subunits of the dome "A" at this sector commonly possess distinct penetrative foliation and stretching lineation. The foliation planes dip towards the NE, N and NW directions; the stereonet plots for their poles exhibit a distinct asymmetrical antiformal structure plunging moderately to the NW (Fig. 6A-a). The contours of their stretching lineation plunging also but shallowly to the NW and SE (Fig. 6A-b).

The northeastern (B) and southwestern (D) sectors of the dome "A". These two sectors build up the northeastern and southwestern limbs of the dome "A" structure (Figs. 6 B,D). Here the measured field data of these two sectors were added together in order to get a best form for their projections. The eastern (B) and the western (D) sectors denote the northeastern and the southwestern limbs of the dome "A", respectively. The foliation of the lithologic subunits forming the northwestern limb possesses relatively smaller amounts of dip and therefore cover a vast surface area compared with those of the northeastern limb (Fig. 3-a). These structural features indicate that the studied antiformal structure of the dome "A" as shown before is symmetrical and with a SW dipping axial plane (Fig. 3-a). This is clearly shown by occurrence of two clusters of poles to foliation (Figs. 6B-a and 6D-a). The pole of the plunging is inclined moderately to NW (Figs. 6(B+D) and 6-b).

The stretching lineation plunge moderately to NW; conformably with the general plunging of the associated major fold axis of the dome "A" whose axial plane dips mostly to SW.

The southern sector (C) of the dome "A". This sector is separated from the southern dome "B" of WHC by an oblique sinistral NE-SW trending strike slip shear zone (Fig. 2). It is composed of complexly folded, foliated and lineated litholoIgic sequence composed mainly of banded migmatized amphibolite layers, up to 10 cm thick, together with minor migmatized granite gneiss intercalation. The axes of the mesoscopic folds generally plunge 50°-55° toward 210° i.e. towards the SSW direction. The poles to foliation define a girdle plane dipping shallowly SW; the axis of the main antiform therefore plunges moderately S to SSW indicating small clockwise rotation toward the SW (Fig. 6C-a) probably due the effect of the intersection of the southwestern margin of the dome "A" by the NE-SW trending sinistral shear zone as shown before.

Shait ophiolitic mélange domain (E) occupies the N, NE and NW parts of the map area. It is represented by curvi-linear nappe assemblages consists of moderately to intensely deformed low-grade metasediments incorporating sheared ophiolitic and serpentinite fragments. The deformed rocks of the nappes show top to the NW tectonic transport direction similar to that of the dome "A" structure as indicated by presence of asymmetric mesoscopic folds, S/C and S/C' fabrics in the foliated calc-alkaline metavolcanics and volcaogenic metasedimentary units occurring in ophiolitic mélange assemblages of Wadi Shait (Fig. 5- a,b). The poles to foliation define moderately dipping girdle plane with moderately NW plunging axis (Fig. 6E-a). The associated stretching lineations plunge at various angles toward the NNW and SSE directions. However, they reflect maxima toward the NNW direction (Fig. 6E-b).

4- DEFORMATION PHASES

Integration of the field and petrographic investigation data collected from the infra- and suprastructural units of the studied area is used to erect the following sequence of deformation events in a chronological order:

4.1 – D1 deformation phase

This phase is concerned mainly with the composition and age of the protoliths of the four structural subunits forming the dome "A" infrastructure and the suprastructural unit of the Shait ophiolitic mélange domain. The subunits of the dome "A" commonly exhibit primary layering structures and are separated by fault contacts. As noted before, the lower most subunit consists of granite gneisses occasionally intercalated by relatively thinner layers of amphibolites, the second subunit is composed essentially of banded amphibolites together with minor intercalational layers of granite gneisses, the third subunit consists of subequal amounts of psammitic gneisses and amphibolite interlayered sequence, whereas the upper most fourth subunit is composed mainly of psammitic gneisses together with minor amphibolite interlayers. The gneiss layers vary in colour from grey to light red, usually heterogeneous and include varying proportion of metamorphic minerals such as quartz, biotite, hornblende, garnet, Ca-feldspars, K-feldspar and in some cases, sillimanite therefore they reflect different sedimentary protoliths such as impure graywackes, calcareous graywackes. The pale red psammitic gneisses of the upper fourth subunit were distinctly derived from disintegration of granitic rocks. Whereas the layered amphibolites were mostly related to calcareous greywackes and/or intermediate tuffs, though other igneous origin cannot be excluded.

The conformable relation of the gneiss and amphibolite layers in the interlayered sequences of the layered structural subunits may be related to the early D_1 deformation episode which preceded the obduction of the Pan-African ophiolite and calc-alkaline island arc cover nappes in the Eastern Desert of Egypt domain (Fritz et al. 1996). During this episode the deposited impure greywacke, calcareous greywacke and intermediate tuff sedimentary layers (S_0) were regionally metamorphosed (M_1a) under medium to high P and T coeval with the dominance of development of diatexitic migmatite types in the lower level and metatexitic migmatites types in the upper level of the dome "A" metamorphic sequence.

The metamorphic foliation (S_1), the accompanying lineation (L_1) and the rootless isoclinal folds (F_1) formed during D1 episode run generally coincident with the orientation of S_0 layering. The rootless isoclinal folds prevailing in the lower two subunits are also considered by Greiling et al. (1984, 1988) and El-Ramly et al. (1993) as structural elements to be cogenetic with the early D_1 deformation phase. The obtained isotopic data show that the age of such M_1a metamorphism of the studied gneisses ranges between 780 Ma and 560 Ma (this work will be submitted in another publication).

The suprastructural rocks of Wadi Shait and Wadi Nugrus ophiolitic mélange domains may represent remnants of obducted giant nappes, generally loosed their stratigraphy under the effect of shearing and thrusting. These obliterated remnants comprise ophiolite, island arc and sedimentary fragments which were subjected prior to their obduction event to non-uniform submarine metamorphism (M_1b); during which gabbros, basalts, calc-alkaline volcanics and trench sediments underwent a buried metamorphism up to the greenschist facies; whereas ophiolitic peridotites were entirely transformed into serpentinites; relict pyroxene, olivine and chromite may occur. Moreover primary layering structure (S_0) in the metamorphosed pyroclastic and sedimentary rocks can easily by traced.

4.2- D2 deformation phase

This phase of deformation is related to the large-scale NW thrusting or large-scale tectonic transport event of the Pan-African ophiolite and volcaniclastic cover nappes over the infrastructural rock units scattered in the Eastern Desert terrane. During this event, the infrastructural units were imbricated into several structural subunits or slices in addition to subjection to severe diaphthoresis and mylonitization.

It is worth to mention that the large-scale thrusting of the Pan-African nappes over the Wadi Hafafit domes in general and the mapped dome "A" in particular caused them to be dynamically or retrogressively metamorphosed (M_2a) into mylonite, protomylonite and augen schists. Consequently, the M_1a progressive minerals such as garnet, hornblende, feldspars and quartz were partially and/or totally transformed into retrogressive ones such as garnet 2, biotite 2 and quartz 2 in addition to development of secondary phases as actinolite, muscovite, sericite and epidote, with a metamorphic grade characteristic of greenschist facies. These mineral phases are generally notable along the main detachment thrust fault zones occurring between the suprastructural nappes and the infrastructural dome "A".

Several remnants of metamorphic mineral phases related to this thrusting event presented as porphyroclasts may exhibit various strain effects as undulose extinction, mechanical twinning, kink bands and L_2 stretching lineation occasionally accompanied by pressure shadows or wrapped around by S_2 foliation.

4.3- D3 deformation phase

This deformation phase is nearly synchronous with the late stage of the Neoproterozoic East African Orogeny ~ 630 Ma in the Arabian-Nubian Shield. In this episode the northwestern Midyan-Eastern Desert terrane of the Shield, whose the Eastern Desert tract is related, has been intersected by NW-SE trending sinistral dominated shear zones (Fritz et al. 1996), formerly known as Najd Fault System. In the study area, as the northeastern bounding Nugrus shear extends NW parallel to and with left-lateral sense of movement similar to the Najd Fault System, one may suggest that the exhumation of the Wadi Hafafit metamorphic domes, in which the present dome "A" is one of these, are exhumed within a crustal-scale wrench corridor of the Najd Fault System. With some details the exhumation of the dome "A" was done under an E-W bulk compression joined by contraction in the eastern part (eastern limb) and extension in the western part (western limb) besides another extension developing at the northern margin. The contraction is illustrated by formation of close folding, and steep inclination of the structural subunits of the northeastern limb of the dome compared with those of the western limb. The western extinction is registered by the dissection of the western limb into several southwestward dipping low-angle normal faults, whereas the northern extension is manifested by development of NW to NE dipping Shait normal fault.

Furthermore, field observations reveal the influence of the Wadi Shait ophiolitic mélange domain by a NW trending large-scale crustal extension illustrated by its transformation into a curved array of elongate subparallel fault-bounded ridges (e.g. Mudargag and Ras Shait ridges) intervened by subsided wadis or ravines. This extensional fault system have a general attitude similar to that of Shait low-angle normal fault, therefore they appear to be coeval with the extensional phase influencing the northern zone of the dome "A". The location of the composite calc-alkaline elongate granite mass of the Mudargag El-Ahmar along the western extension of one of these noted faults indicates its intrusion within the same episode of the crustal extensional event of the Wadi Shait ophiolitic mélange domain. Again, the formation of these transtensile structures can be interpreted by the termination of the Nugrus strike-slip fault at its NW end portion into a series of splays with left-sense of movement similar to the main Nugrus fault.

5- SUMMARY AND CONCLUSIONS

Field and petrographic investigations implemented on the Mudargag area manifest the following interesting points:

The dome "A" infrastructures of the WHC forms a NW-SE trending antiformal structure and tecto-stratigraphy consists of four structural subunits derived mainly from less mature sedimentary parentages, however, igneous protoliths are infrequent and are expected only as a secondary origin for some amphibolites, particularly those of subunit 2.

The dome "A" subunits exhibit medium to high-grade of metamorphism (M_1) and structurally underlie the suprastructural unit of Shait ophiolitic mélange domain which is dominantly characterized by greenschist facies of metamorphism (M_1b). Moreover, the metamorphosed dome "A" protoliths were plastically to brittlely mylonitized and diaphthorized (dynamic metamorphism M_2) due to large-scale NW thrusting of the napped ophiolitic mélange during the main stage of the Pan-African or East African Orogeny. The age of this mylonitization event was assumed to be 630.8 ± 2 Ma i.e. the age of the granite protoliths in the Meatiq Dome (Andresen et al., 2009).

In agreement with the orogen-parallel extension model (Wallbrecher et al., 1993; Fritz et al., 1996, 2002; Loizenbauer et al., 2001; Bregar et al., 2002; Abdel Wahed, 2008) the Wadi Hafafit culmination to which the dome "A" is associated was exhumed together with the northern ophiolitic mélange within a left-lateral dominated wrench corridor of Najd fault system coeval with development of the SW- dipping of a normal fault array and Shait low-angle normal fault at its southwestern limb and the northern margin; respectively. Moreover, the up-domning of the Shait ophiolitic mélange was also accompanied by its slicing up into a series of curved-bounded faults formed in response to a transtensional regime related to the branching off of the NW-end of the Nugrus fault into a group of a northwest-ward trending horse-tail splays.

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التطور التكتوني التحولي للقبة (أ) التابعة لمجموعة وادي حفافيت ومنطقة ميلانج شعيت الافيوليتية المجاورة اثناء فترة النيوبروتيروزويك – جنوب الصحراء الشرقية – مصر

تتكون منطقة جبل مدرجج (٧٤٠كم٢) من وحدتين صخريتين تكتونيتين مفصولتين بفالق قذفي افقي يميل مستواه قليلا في اتجاه الشمال الغربي.

وتعرف الوحدة التكتونية السفلية بالقبة (أ) التي تتبع مجموعة قباب وادي حفافيت، حيث تتواجد على هيئة طية كبيرة محدبة غير متماثلة ، يبلغ طول محورها الرئيسي حوالي ١٠كم في اتجاه الشمال الغربي. وقد حللت صخور هذه القبة الى حوالي اربعة وحدات تكتونية صغرى يغلب على تركيبها الصخري الاصل الرسوبي. وان هذه الوحدات تكون متأثرة بتحول اقليمي يتراوح درجته من الرتبة المتوسطة الى العليا. وتبدا الوحدات الصغرى بوحدة النيس الجرانيتي يليه الى اعلى وحدة الامفيبوليت ثم وحدة النيس البزميتي المتبادل مع الامفيبوليت واخيرا تأتي الوحدة العليا التي يغلب عليها النيس البزميتي .

اما الوحدة التكتونية العلوية فتتمثل بوحدة ميلانج شعيت الافيوليتية التي تحتوي على اجزاء صخرية مشتقة من صخور الجزر القوسية وصخور الافيوليت والتي يتراوح تحولها الى رتبة الجرينشيست المنخفضة.

وقد بينت الدراسات البتروجرافية والتركيبية على ان صخور الوحدتين التكتونيتين قد مرت ثلاث مرحل من التشوه (D1—D3)، كما ان تكون القبة (أ) وتحولها التهشمي وانفصال وحدة ميلانج شعيت الافيوليتية الى تلال صخرية متوازية تنفصل بفوالق شدية يرجع اساسا الى تجاور المنطقتين بواسطة فالق نجرس المضربي اليساري الذي يوازي فالق نجد الرئيسي ذى الحركة اليسارية ايضا.